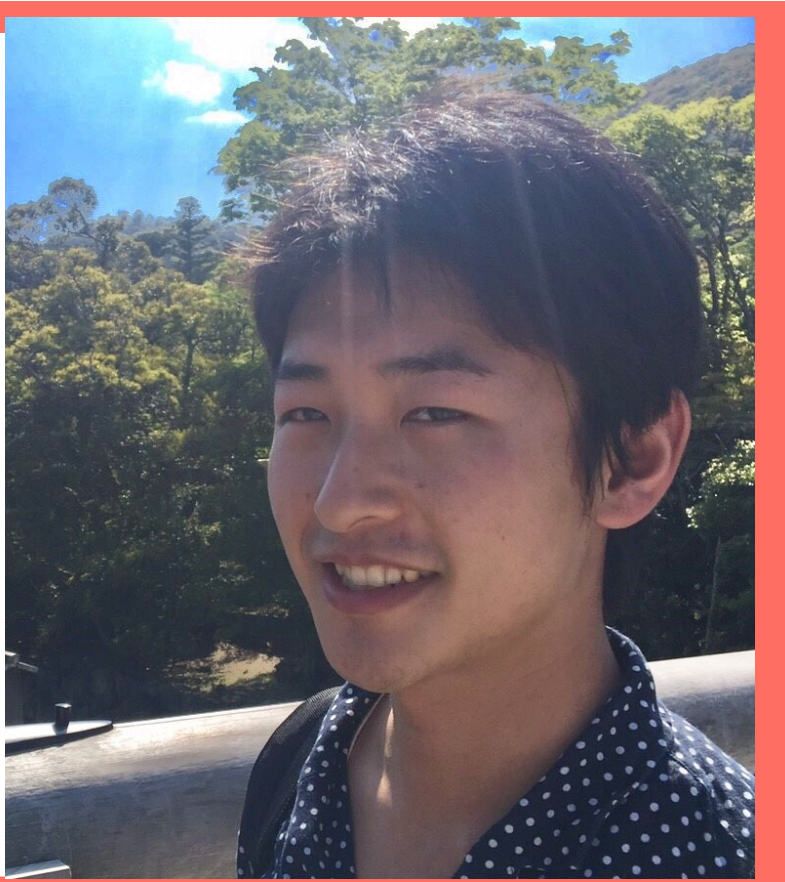


# Isophote Shapes of Early-Type Galaxies in Massive Clusters at $z \sim 1$ and 0

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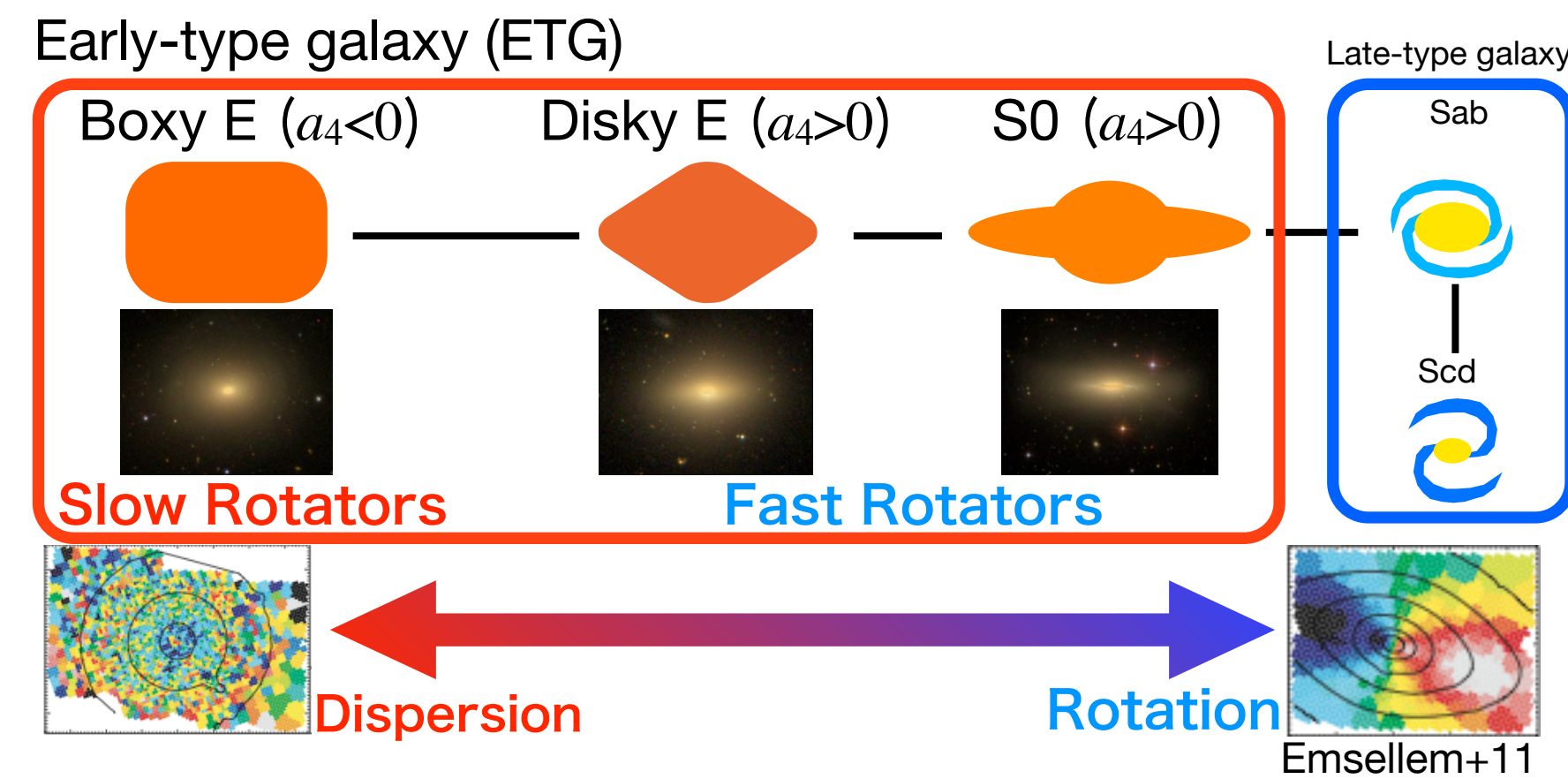
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(3) Stanford University



Dynamics of early-type galaxies (ETGs), whether they are supported by rotation or dispersion, is a clue to understand their assembly history. We compare the isophote shape parameter  $a_4$  between  $z \sim 1$  and 0 as a proxy for dynamics to investigate the epoch at which the dynamical properties are established. We create cluster ETG samples with stellar masses of  $\log(M_*/M_\odot) \geq 10.5$  with spectroscopic redshifts. We have 130 ETGs from the Hubble Space Telescope Cluster Supernova Survey for  $z \sim 1$  and 355 ETGs from the Sloan Digital Sky Survey for  $z \sim 0$ . We find similar dependence of the  $a_4$  parameter on the mass at  $z \sim 1$  and 0; the main population changes from disk ( $a_4 > 0$ ) to boxy ( $a_4 \leq 0$ ) at a critical mass of  $\log(M_*/M_\odot) \sim 11.5$  with the massive end dominated by boxy ETGs. The disk ETG fraction is consistent between these redshifts. Although uncertainties are large, the results suggest that the isophote shapes and probably dynamical properties of cluster ETGs are already in place at  $z > 1$  and do not significantly evolve in  $z < 1$ , despite significant size evolution. The constant disk fraction imply that the processes responsible for the size evolution is not enough violent to convert the dynamical properties of ETGs.

## ① Introduction

### • Dynamics and shapes of early-type galaxies (ETGs)



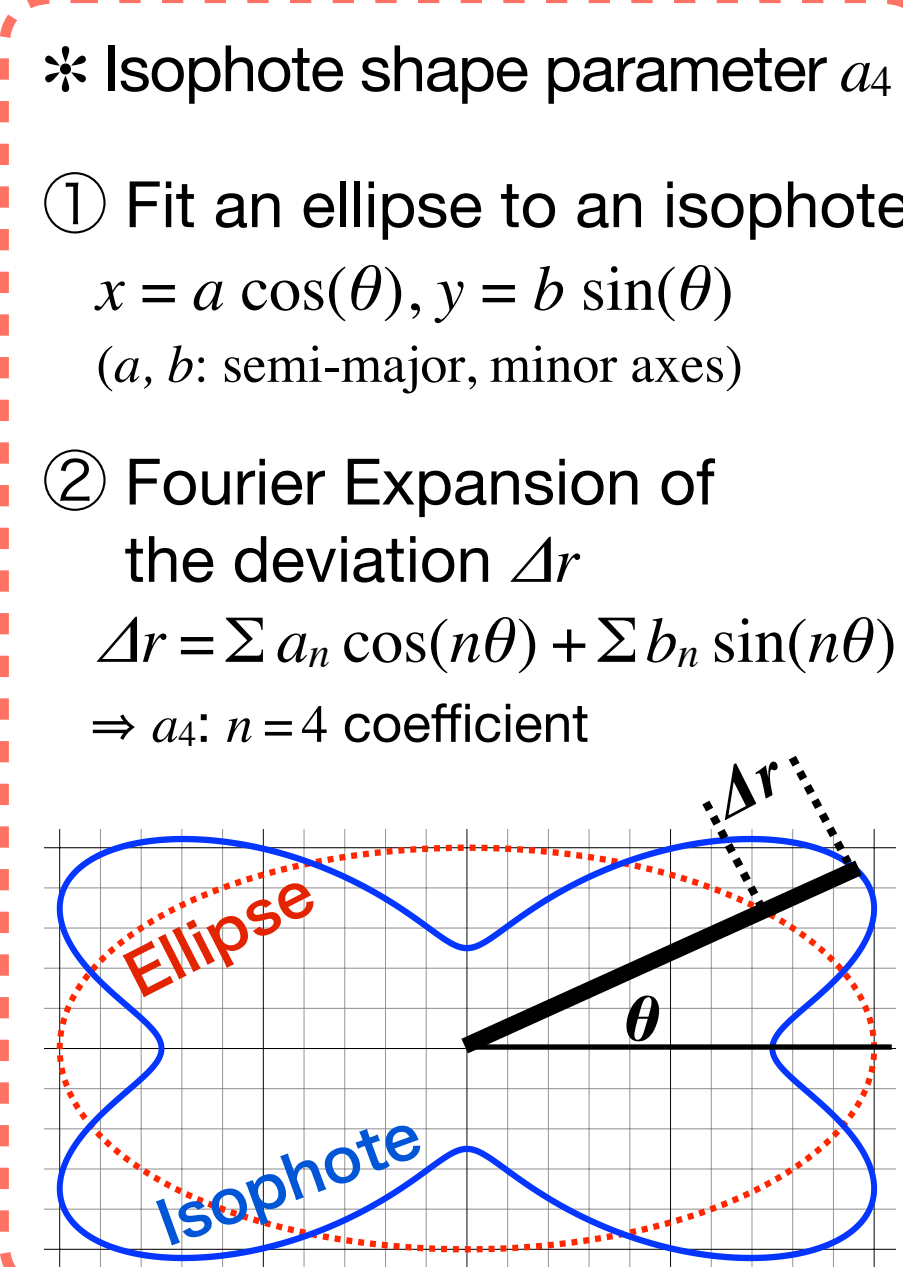
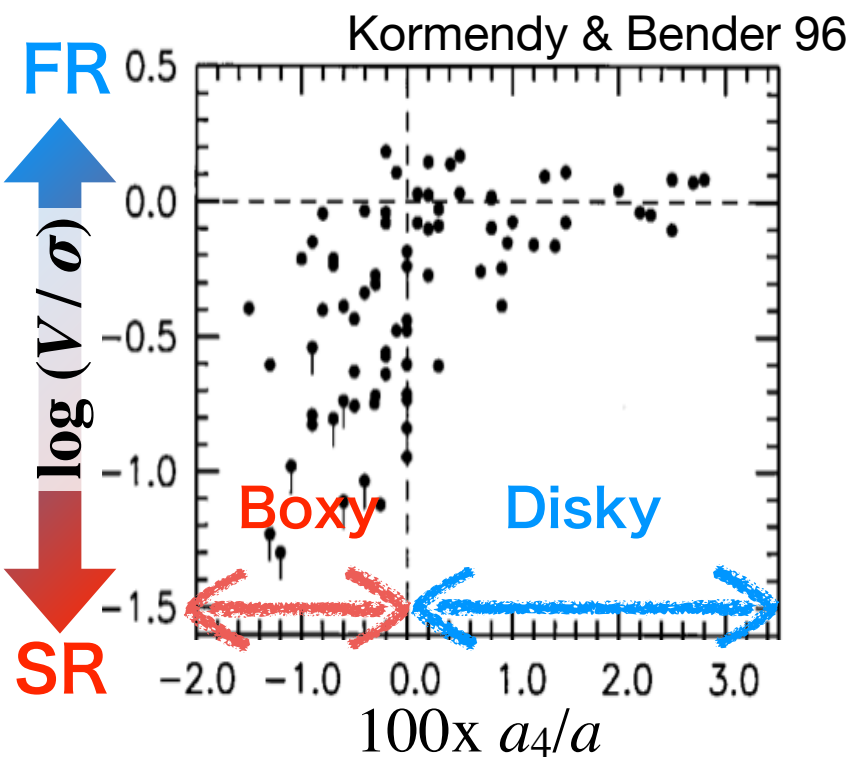
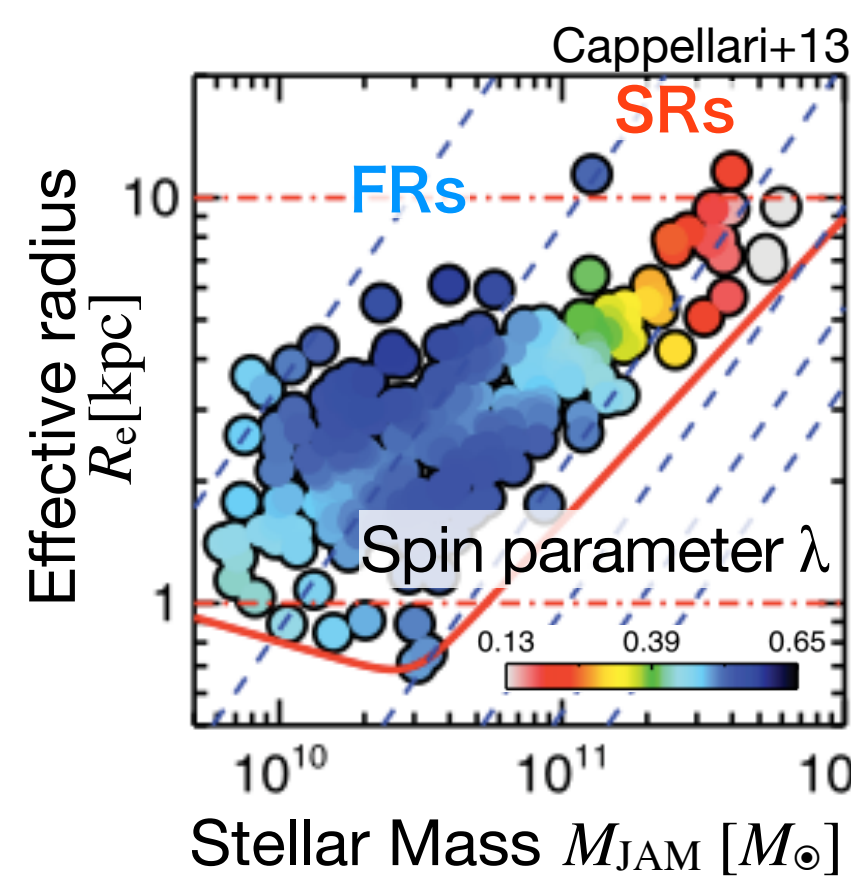
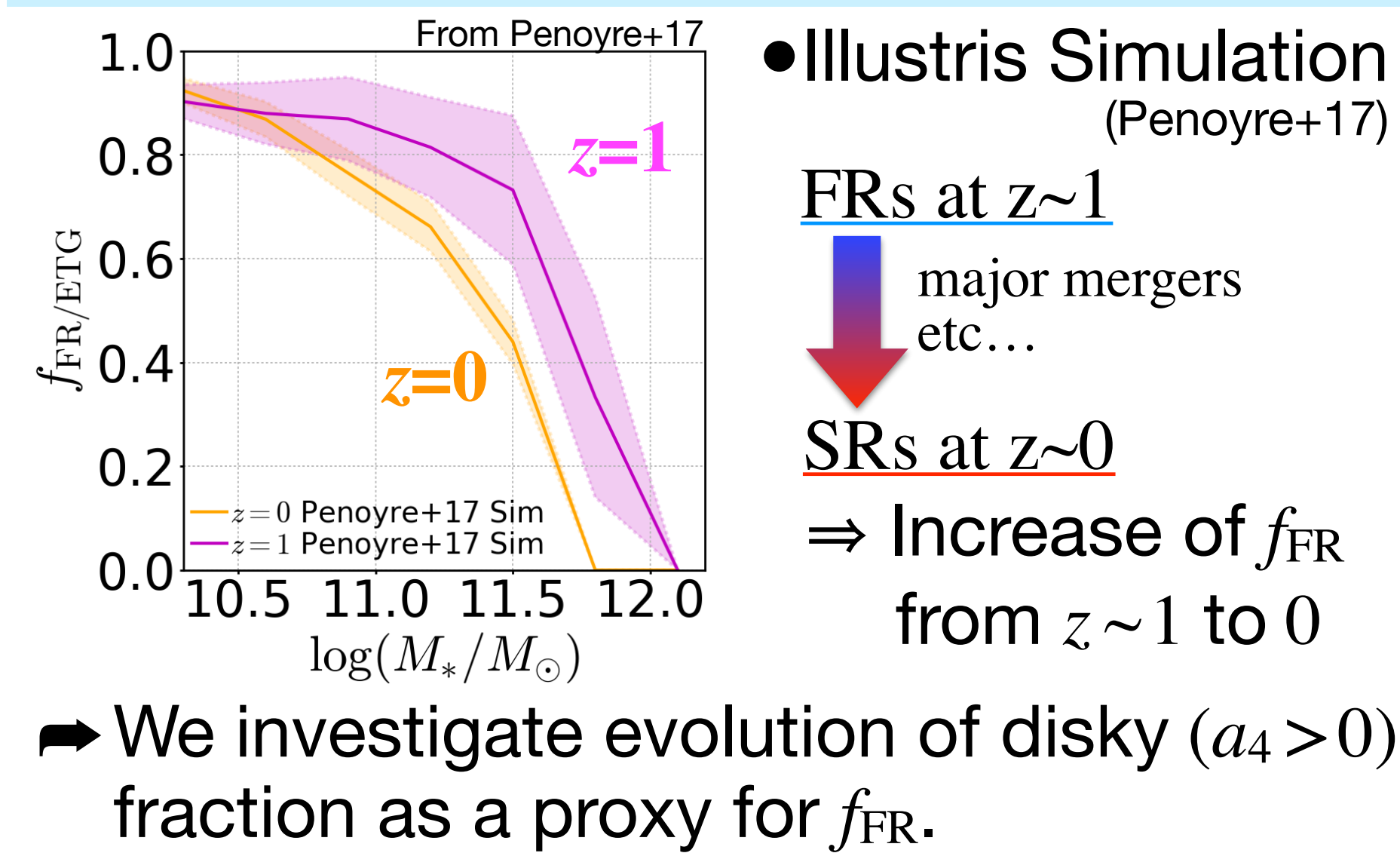
#### Slow rotators (SRs)

- Massive:  $\log(M_*/M_\odot) > 11.3-5$
- Tend to be boxy:  $a_4 < 0$

#### Fast rotators (FRs)

- Less massive:  $\log(M_*/M_\odot) < 11.3-5$
- Tend to be disk:  $a_4 > 0$

### • Evolution of FR fraction: $f_{FR}$



## ② Sample & Method

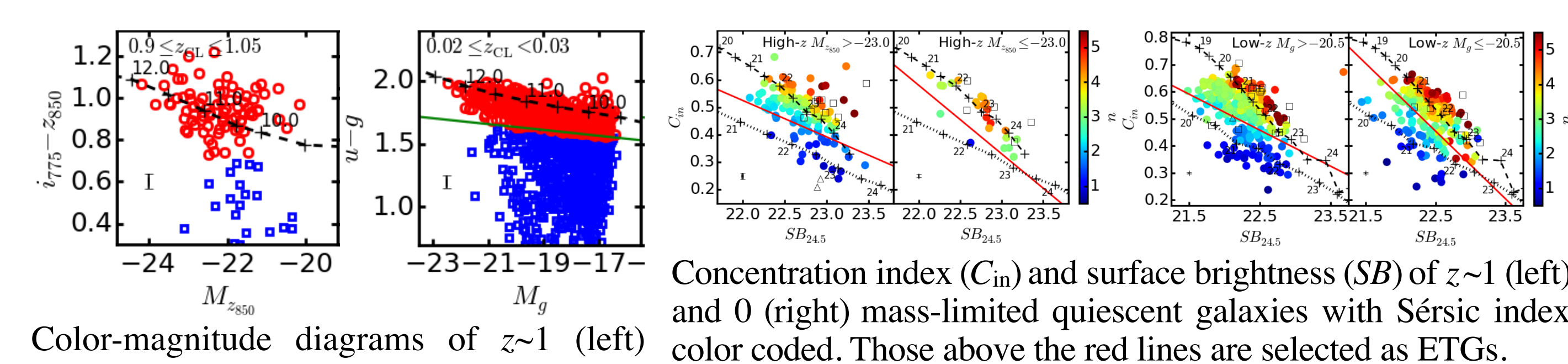
### • $z \sim 1$ and 0 Cluster ETG Samples

$z = 1$ : HST Cluster Supernova Survey (Dawson+09)

- ▷ 19 clusters at  $0.9 < z < 1.4$   
 $\log(M_{200}/M_\odot) \sim 14.2-14.9$  (Jee+11)
- ▷ 301 galaxies with spec.  $z$   
red sequence selection with  $i_{775}-z_{850}$  vs  $z_{850}$  diagram
- ▷ 224 quiescent galaxies  
 $M_*$  limit:  $\log(M_*/M_\odot) > 10.5$
- ▷ 158 mass limited sample  
concentration index and surface brightness selection
- ▷ 130 ETGs

$z = 0$ : Sloan Digital Sky Survey

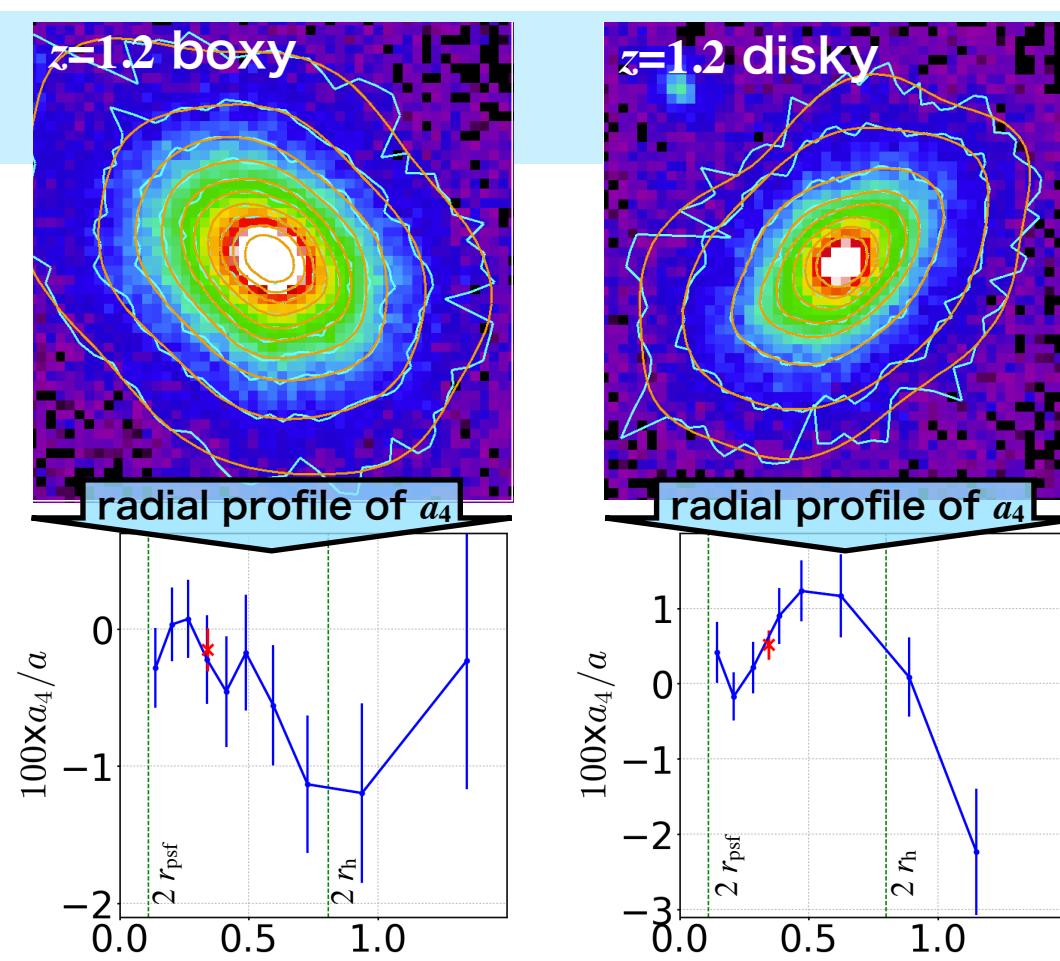
- ▷ 9 clusters at  $0.02 < z < 0.05$   
 $\log(M_{200}/M_\odot) \sim 14.6-15.2$  (Reiprich & Böhringer 02)
- ▷ 3728 galaxies with SDSS spec.  $z$   
red sequence selection with  $u-g$  vs  $g$  diagram
- ▷ 1733 quiescent galaxies  
 $M_*$  limit  $\log(M_*/M_\odot) > 10.5$
- ▷ 513 mass limited sample  
concentration index and surface brightness selection
- ▷ 355 ETGs



Color-magnitude diagrams of  $z \sim 1$  (left) and 0 (right) galaxies. Red symbols are selected as quiescent galaxies.

### • Measuring $a_4$ parameter

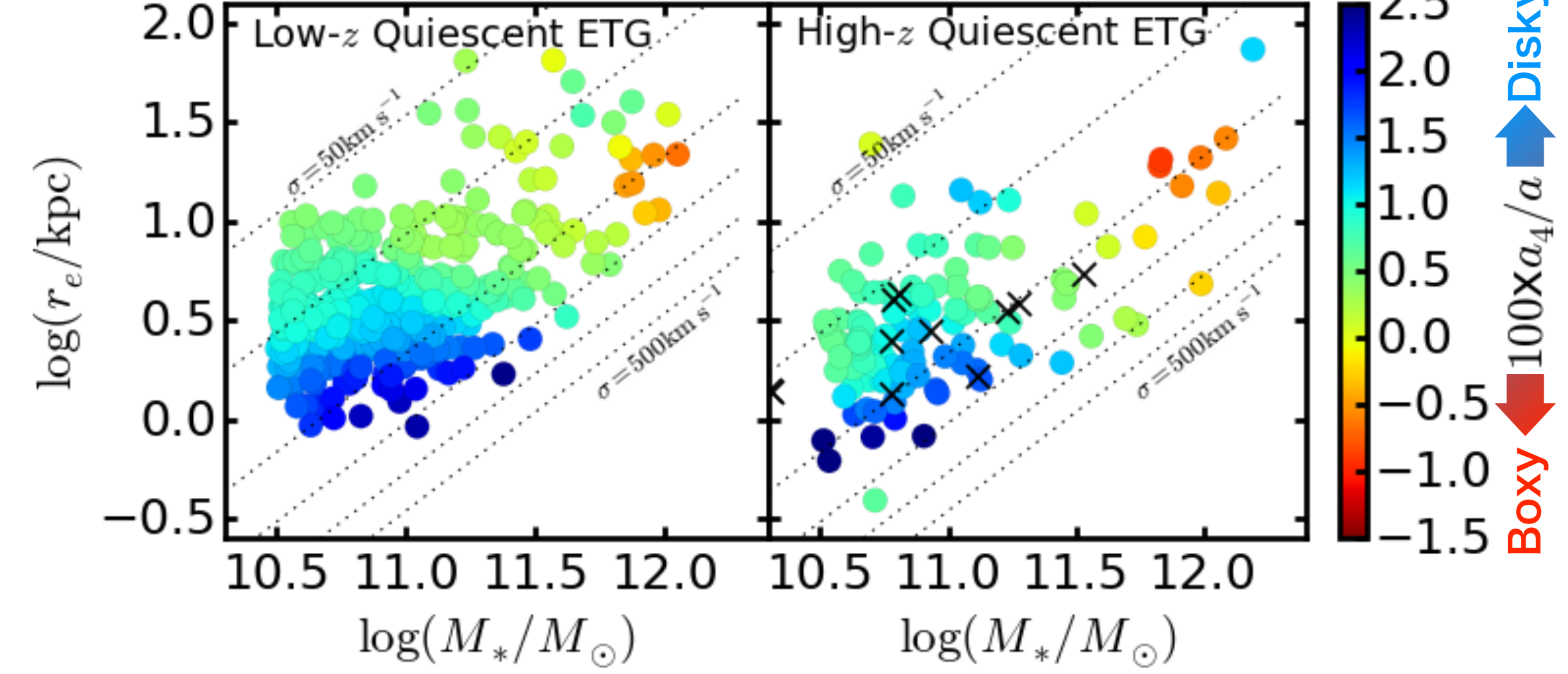
- ① Determine isophote contours  
 $z \sim 1$ : HST  $z_{850}$  image,  $z \sim 0$ : SDSS  $g$  image  
(Right figures: example of  $z \sim 1.2$  galaxies)
- ② Fit ellipses with Fourier deviation  
Radial profiles of  $a_4$  parameter etc... are derived.
- ③ Get mean  $a_4$  value from radial profile  
Luminosity weighted mean within  $2 r_{PSF} < r < 2 r_h$   
\*  $r_{PSF}$ : 0.5 PSF FWHM,  $r_h$ : half-light radius



## ③ Results & Discussion

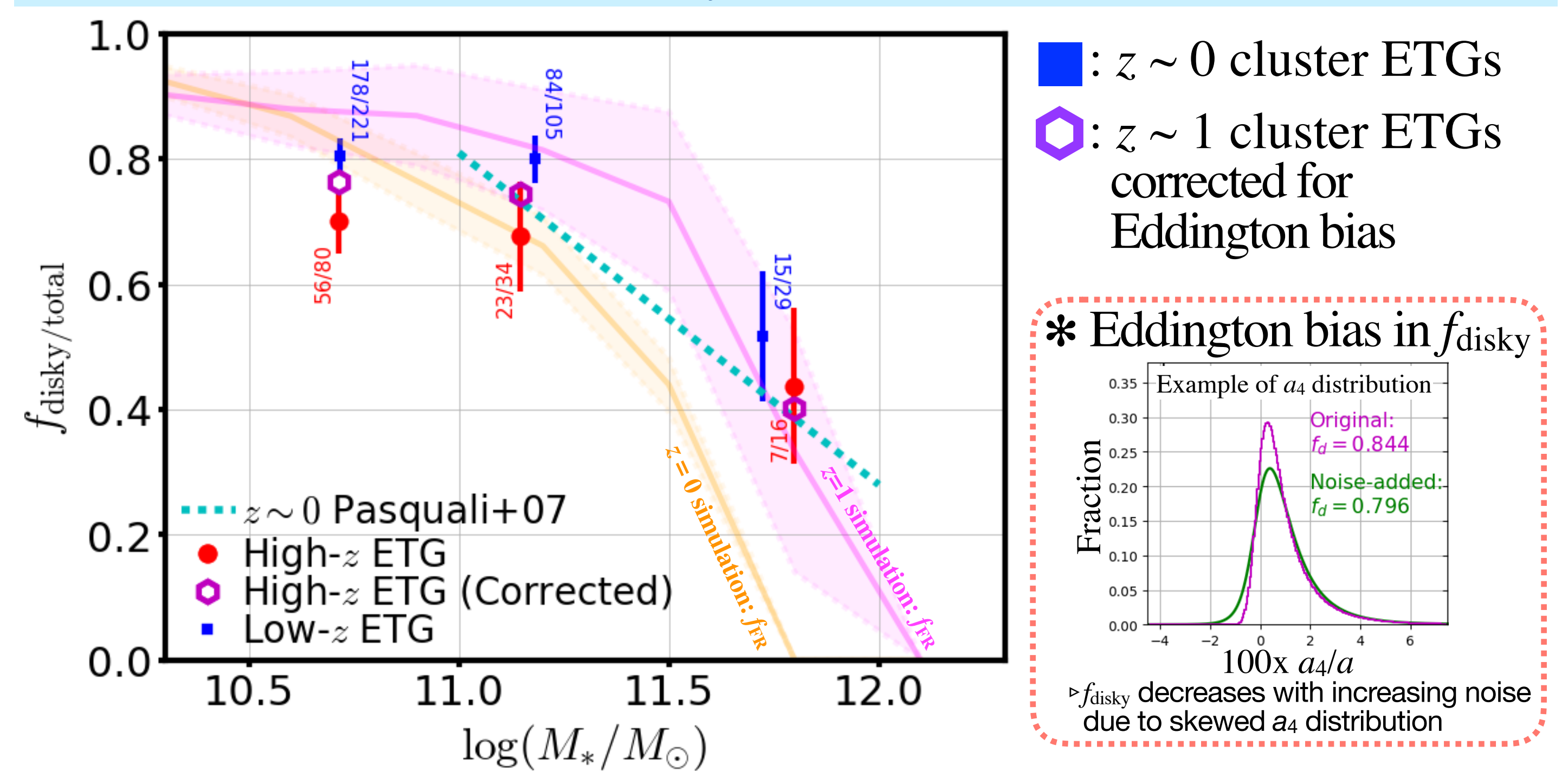
### • Dependence of $a_4$ parameter on mass and size

↓ Averaged  $a_4$  value color coded on the size-mass plane



- ▷ Massive end ( $\log(M_*/M_\odot) \geq 11.5$ ) is dominated by boxy ETGs both for  $z \sim 0$  and 1.
- ▷ For less massive ETGs, smaller galaxies tend to be more disk with larger  $a_4$  value both for  $z \sim 0$  and 1.
- ▷  $z \sim 0$  sample has galaxies with large sizes ( $\sigma \sim 50 - 100$  km/s).  
→ recently ( $z < 1$ ) quenched galaxies?

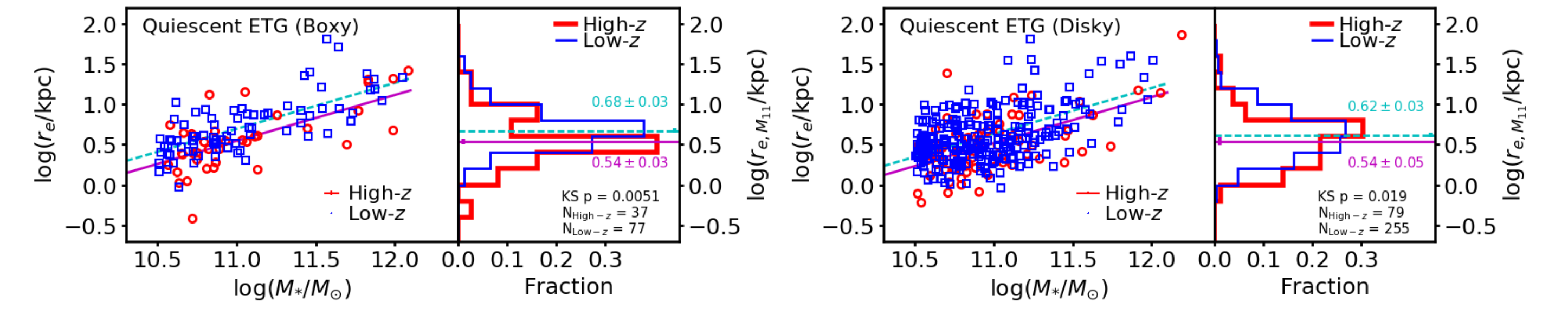
### • Disk ETG fraction ( $f_{disk}$ ) at $z \sim 0$ and 1



- ▷ Disk fraction is consistent between  $z \sim 0$  and 1 within uncertainty taking account of Eddington bias (no significant evolution in  $z < 1$ ).
- ▷ Boxy shapes of massive ETGs are already in place at  $z > 1$ .
- \* Isophote shapes (boxy/disk) may not reflect dynamical states (SR/FR), taking account of the discrepancy between  $f_{disk}$  in observation and  $f_{FR}$  in simulation at  $z = 0$ .

### • Size evolution of the ETG samples

↓ Size-mass relation and normalized size distribution of boxy/disk ETGs



- ▷ Significant size evolution from  $z \sim 0$  to 1 (both in boxy and disk)  
⇒ processes of the size evolution may not be very violent (e.g., minor mergers rather than major mergers) considering constant disk fraction from  $z \sim 0$  to 1.

## Refereces

K. Mitsuda et al., 2017, ApJ, 834, 109; E. Emsellem et al., 2011, MNRAS, 414, 888; M. Cappellari et al., 2013, MNRAS, 432, 1862; J. Kormendy & R. Bender 1996, ApJ, 464, L119; Z. Penoyre et al., 2017, MNRAS, 468, 3883; R. Bender & C. Möllenhoff 1987, A&A, 177, 71; K. S. Dawson et al., 2009, AJ, 138, 1271; T. H. Reiprich & H. Böhringer, 2002, ApJ, 567, 716; M. J. Jee et al., 2011, ApJ, 704, 672; M. Doi et al., 1993, MNRAS, 264, 832; A. Pasquali et al., 2006, ApJ, 636, 115; A. Pasquali et al., 2007, ApJ, 664, 738; J. Kormendy et al., 2009, ApJS, 182, 216; T. Naab & A. Burkert 2003, ApJ, 597, 893; S. Khochfar & A. Burkert 2005, MNRAS, 359, 1379; T. Naab et al., 2014, MNRAS, 444, 3357; S. Khochfar et al., 2011, MNRAS, 417, 845;